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FIGS. 7 and 8.—Germinating spores on May 5th, showing variations in mode of division.
" 9 and 10.—Young prothallia on May 8th.
" 11 and 12.—Young prothallia on May 8th, showing early branching.
FIG. 13.—Short, thick prothallium (May 8th).
" 14.—Young prothallium, much elongated (May 8th).
All the figures magnified 125 diameters.

EXPLANATION OF PLATE II.

FIG. 15.—Branching prothallium, May 18th.
" 16.—Branching prothallium, showing protoplasm condensed in the ends of the cells, May 24th.
" 17.—End of branch of older prothallium.
" 18.—Young antheridium.
" 19.—Antheridia; *a*, unopened; *b*, opened, with escaping antherozoid cells, June 13th.
" 20.—Prothallium with antheridia and antherozoids, June 10th.
" 21.—Antherozoids, mag. 350.
All the figures excepting Fig. 21 magnified 125 diameters.

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ON THE GEOLOGICAL EFFECTS OF A VARYING ROTATION OF THE EARTH.

BY PROFESSOR J. E. TODD.

THE fact of variation in the velocity of the earth's rotation, seems so nearly established as to call for a consideration of its effects on geology. One can scarcely read Professor Newcomb's masterly paper on the acceleration of the moon without feeling that the ability of astronomers to state the exact times of eclipses, especially of those in past time, has been greatly overrated. As he himself says in conclusion, "If Hansen is right, then Ptolemaic eclipses might be harmonized, but the Arabian would be ten to fifteen minutes out of the way, which to my mind seems very improbable. Apparently, therefore, we can hardly avoid accepting one of these propositions: Either the recently accepted value of the acceleration, and the usual interpretations of the ancient solar eclipses are to be radically altered, the eclipse of — 556 not having been total at Larissa, and that of — 584 not having been total in Asia Minor; or the mean motion of the moon is, in the course of centuries, subject to changes so wide that it is not possible to assign any definite value to the acceleration."[1]

We learn from this same paper reasons for believing that the earth lost seventeen seconds in its rotation between 1750 and 1800, and has gained thirty-one seconds since 1800 A.D.[1] Also, that much greater variations may have taken place in the past, and yet escaped the observation of astronomers:

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[1] Newcomb. Observations on the moon before 1750, p. 278. (Washington Ast. and Met. Observations, Vol. XXII, App. II.)

Mr. G. H. Darwin, in his paper on the Precession of the Viscous Spheroid, and on the remote history of the earth,[2] shows that if we assume a viscosity for the earth, such that a cubic inch, when subjected to a force of 13½ tons, would be distorted $\frac{1}{10}$ of an inch in twenty-four hours, and that such viscosity has remained constant, the retardation of the rotation of the earth has been such that 46,300,000 years ago a sidereal day was fifteen hours thirty minutes, and a sidereal month 18.62 days. As Mr. Darwin remarks: "It seems that we have only to postulate that the upper and cooler surface of the earth presents such a difference from the interior, that it yields with extreme slowness, if at all, to the weight of continents and mountains, to admit the possibility that the globe on which we live may be like that here treated of." Hence we may start with the assumption that not only is the rotation of the earth variable, but this variation is considerable.

It is proposed to present, in the treatment of our subject, first, a theoretical discussion of the case, secondly, a survey of related facts, and finally, suggestions to direct further investigation of the matter.

I. The rotation of the earth may be considered as the result of gravitation condensing it from its original nebulous or gaseous condition, The check to condensation we may consider to have been originally the expansive power of heat and the centrifugal component of its force of rotation. Now, however, we find the equilibrium of rotation lying between the following forces:

Forces affecting the rotation of the Earth. Those tending to accelerate are:

First. The contraction of the earth, especially in low latitudes. This, now, as in all past ages, is doubtless the main force on this side.

Second. The transfer of matter of any kind, from lower to higher latitudes. This may be (1) either by the transfer of liquid matter in the interior, attending a local depression of the earth's crust in lower latitudes, or (2) a transfer of water, either as vapor, water or ice, by some secular change in the earth. For example, the accumulation of ice at the poles during the glacial period. It should be noted here, that the circulation of ocean currents and aërial currents have no effect, so long as the sea-level remains constant. Every current, however strong, or whatever its direction, is counteracted by others. (3) A third case under this head, is the transfer of sediment, either by river or ocean currents. All streams flowing toward the poles conspire to this effect. The higher the latitude the more efficient the stream, other things being equal, but as the erosion is diminished by the cold, those in middle latitudes are probably the most efficient.

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[1] See also *Am. Journ. of Sci.* (III), XIV, p. 408.

[2] Phil. Trans., Vol. 170, Part II.

On the other hand, retarding influences are as follows:

First, and most unquestioned—the friction of the tides. The conditions in which this force would be most efficient have not, so far as the writer is aware, been satisfactorily stated. An alternation of oceans broad enough to accumulate the wave to its utmost, and of narrow continents, with shores adapted to raise the water to its highest point, and wholly check its flow, would seem perhaps the most favorable.

Second. The transfer of matter of any kind from higher to lower latitudes. The remarks made under the head corresponding, above, will apply equally well in this case.

Third. Any elevation of the earth's crust, either local or general, in lower latitudes, resulting either from increased heat, as near volcanoes, or from any bending of the earth's crust. If in the latter case, both the anticlinal and synclinal folds of the crust are in the same latitude, no change in rotation would result.

Fourth, and last, but by no means least, we would rather say greatest, a distortion of the earth's body by the attraction of the sun and moon. The degree of viscosity assumed by Mr. Darwin would seem to be little enough to satisfy the most ultra rigidarian or uniformitarian, and if a more yielding condition be predicated of the earth, certainly its effect will be indefinitely magnified.[1] Whether instruments will ever be invented delicate enough to measure its amount is doubtful.

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[1] That this force is really efficient at the present time is attested by the influence of a variation in distance of these bodies on the occurrence of earthquakes. From the researches of Perrey, Volger and others, we learn that earthquakes are much more numerous when the earth is near perihelion than when near aphelion, and that they occur more frequently and with more violence when the moon is in perigee than at other periods.

To illustrate the efficiency of these different forces, we may refer briefly to the following calculations: The sinking of the equator 110 feet would shorten the time of rotation of the earth one minute, or if it was retarded one minute per day, it would produce eventually a depression of the equator 110 feet.[1] Erichson estimated that if the center of the Mississippi basin were 45° 55′, and its mouth 29° 8′, the sediment brought down by it would retard the earth .00036 of a second in a century. Ferrel, in 1853, assuming that the tide caused by the moon in the open sea is two feet in height, and that it is highest two hours after the culmination of the moon, showed that it would retard the earth at the equator fifty miles in a century.[2] For the retarding effect of the sun and moon on a viscous earth, see reference above to Darwin's paper.

2. *A Theoretical View of the Action of these Forces.*—We may conceive, therefore, the earth rotating in unstable equilibrium between these sets of forces. As will be seen presently, any change produces effects which tend to counteract the forces causing it. If the earth were wholly fluid, only two of the influences enumerated would remain, and they are those conceived to be most efficient now, viz., contraction from loss of heat, and disturbance from the effect of the moon and sun. A varying ellipticity would exist, because of the varying distances of the sun and moon on the one hand, and the cooling on the other, and there would be more or less regularity in this variation of ellipticity as the earth approached or receded from the sun or moon, in the movements of revolution. As soon, however, as the earth became a solid and rigid mass, as at present, either a decrease or increase of ellipticity would first show itself in the shifting of the waters of the ocean, so that the sea-level only would describe the resulting figure.

That is, if the earth were nearly perfectly rigid, and the rotation diminished continually, the sea-level would be continually lowering at the equator, and rising at the poles. If, on the other hand, by some cause the velocity of rotation were accelerated, the waters would rise at the equator and sink at the poles. By a little calculation, it will be found that the regions where the sea-level would remain approximately stationary, would be near thirty degrees of latitude. It would describe a see-saw movement, as it were, around those parallels. The variation in altitude at the equator would be about one-half as much as at the poles, in any change in which the volume of the earth remained the same.

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[1] Compare *Am. Jour. of Sci.* (III), XII, p. 353.

[2] Newcomb, Reduction and Discussions of Observations on the Moon before 1750, p. 11.

A decrease of velocity of rotation would, in this way, eventually lift the tropical lands so high above the sea, that their weight would become a force sufficient to cause their depression, which, in time, would either lift the tropical sea-beds, or the higher latitudes of both land and sea-bottom.

The former would have little effect to accelerate the earth's rotation, because the average altitude of equatorial continents and seas would remain the same. It would, however, have the effect to drive the waters still more toward the poles. Eventually, however, if not at first, equatorial lands would sink, at the expense of raising higher latitudes, and acceleration would result. This depression, when begun, would probably go beyond the point just sufficient to establish equilibrium in the earth's crust, and would continue, even while the rotation was being accelerated by the depressions. For momentum, in all known cases of vibration, carries the vibratory body beyond the point of rest. Any increase of acceleration would be closely followed by a rise of the sea-level, within the tropics, and a lowering of the sea-level outside, increasing in amount toward the poles. This, with the extra fall of the tropical crust, would turn the tide, eventually, to such an acceleration, that the polar regions would be much elevated above the sea, and in time they would begin to sink from their weight. This would become a retarding influence, which, with the continued retarding influence of the sun and moon, would produce a transfer of water to the higher latitudes, and so the cycle of one vibration would be complete. Now, if these two forces alone should act upon sea and land, there would be, on the whole, a running down, a graduation of vibrations into rest, only to be occasionally broken, perhaps, by varying astronomical relations; but another feature comes in to keep the great double pendulum swinging. The contraction of the earth will accelerate, by the depression of the tropical regions, and retard by depression of higher latitudes. This, therefore, would be a force to keep this vibration continued. The efficiency of this force can scarcely be questioned, at least for the earlier geological epochs, when we think of the folds and faults of ancient strata. Thus far, we have not considered the effect of the movement of the waters, transfer of sediment, etc. The latter would be of comparatively slight efficiency, as before stated. The former would be considerable, and might act as a counter check, and in this way produce slight vibrations, superimposed, as it were, on those of more importance, which we have just considered.

These general movements of land and water need not conflict materially with the various local movements, which have been so clearly defined by various geologists. For example, the local folding of strata, and the elevation of mountains and continental plateaus; areas rising from local heating in the vicinity of volcanoes, and, on the other hand, depressions resulting from the accumulation of sediment.

These, in all ages, must have been numerous. Over areas where both the general and the local influences were acting, of course the result would be the algebraic sum of the two. Perhaps further investigations may discover that certain so-called local movements are indirectly the result of the general influence supposed. For example, in the downward movement of either high or low latitudes, we have supposed that it was attended with and partially the result of, contraction of the earth. This would be likely to be attended with an elevation of mountain ranges. The elevations along the lines of volcanoes crossing the tropical regions at the present time may, perhaps, be considered examples of such action. Another point should be added before we attempt a practical application of our theory. The neutral belts, as they may be called, between the areas of apparent elevation and depression, with respect to the sea-level, will be very variable. Some reasons for the variability will be, (1) The different ellipticity of the earth, at different ages; (2) The amount of contraction of the earth in any vibration; (3) The different capacities of ocean beds in different latitudes, and the consequent varying rate of change in the sea-level. This would affect especially the sea-level at the neutral belts.

II. So much for the theory. Let us proceed to compare it with recorded facts.

1. Changes during the present Epoch.

The first attempt to map the areas of depression and elevation was made by Darwin, soon after his interesting observations on coral islands. His map has been often copied. From this, and the statements of numerous recent observers, we may establish the following generalizations:

1. Areas closely adjacent to active volcanoes, with very few exceptions, are rising. For example, Sunda islands, Sandwich islands, Philippines, West Indies, Central America, etc.

2. Extensive alluvial, and marine plains, rapidly formed, seem frequently to be areas of subsidence. For example, deltas of the Po, Indus, Ganges and Mississippi, Holland (?), New Jersey (?), North Carolina (?).

3. All islands, not volcanic, between the parallels of 30° latitude, bear signs of recent sinking; except Ceylon, of which some, however, report evidences of sinking, and Madagascar, which shows evidence of recent extinction of volcanic action.

4. The continents, within the same boundaries, not infrequently show signs of sinking. The Great Barrier reef testifies to the sinking of Northern Australia. From tropical Africa little is reported which bears upon our case.

South America is reported as sinking at the mouth of the Amazon, by Agassiz; as being bordered with barrier coral reefs, from Abrolhos islands to the equator, by C. F. Hartt. A sunken sandstone reef at Pernambuco, underneath the present one, is reported by J. C. Hawkshaw. Demerara is protected by dikes from the encroaching sea (F. M. Endlich). Upon the west side of the continent, although it may be considered a volcanic area, Von Tschudi reports a subsidence of the coast, at Peru, since its discovery. Bousingault, Proctor and Orton consider that there is strong evidence that the Peruvian and Columbian Andes have sunk considerably since the visit of Humboldt. Darwin reports a depression of Callao, by the earthquake of 1746.

Some exceptions should be noted under this head. Texas is reported to be rapidly rising. This may be due to its nearness to the probably rising axis of the Rocky mountains, which encroaches upon the tropical area. India seems to be rising at several points, as at Bombay, Sinde, Orissa, &c.

5. Areas outside of about 30° latitude are very generally rising. Avoiding, for the present, those near volcanoes, we enumerate:

In the northern hemisphere: Scandinavia, Scotland, France, Spain, North Africa (Reclus), Russia (Murchison), Spitzbergen (Lamont), Franz-Joseph-Land (Howorth), Siberia (Wrangell), Saghalien and Manchooria (Smidt), North China and Japan (Pumpelly) Alaska (Dall), British Columbia (G. M. Dawson), California (Newberry), Hudson's Bay region (Bell), North Greenland (Kane), Labrador (Packard), Nova Scotia (Hind), New England[1] (Shaler).

In the southern hemisphere: Southern New Zealand (Haast), Southern Australia, Melbourne (Becker), Natal (Griesbach), Chili, Southern La Plata, and Patagonia (Darwin).

Some exceptional regions may be mentioned. A few have already been noted under a previous head, which may explain their occurrence. But the sinking of South Greenland, Southern Sweden, and others can scarcely be so explained. It seems better to refer them to local foldings of the earth's crust, which are progressing rapidly enough to neutralize the general elevation of higher latitudes.

From this survey we come very readily to the conclusion, that the facts confirm our theory, for an acceleration of the earth's rotation. Such, it will be remembered, is indicated by recent astronomical observations. And if it is objected, that it is believed that there has been a retardation for ages previous, we may reply, that the evidence is wanting, or at best, indecisive,[2] except for a very short time preceding this century. A brief counter-movement in a period of prevalent acceleration, would be no more than our theory would provide for.

We may therefore glance backward through the ages to further test our theory.

2. *Changes in the Early Quaternary.*

Preceding the present epoch, most geologists find abundant evidence of a depression, in high latitudes, at least in the Northern hemisphere, and far below the present altitude. The evidence from the southern hemisphere, for obvious reasons, is not so abundant. Yet Darwin gives very clear evidence for this point, from Patagonia, and Haast reports a similiar movement in New Zealand, and probably in southern Australia. There is equally abundant and reliable evidence, of a period of elevation of the same regions, in the age preceding the depression just mentioned, and to an altitude far exceeding the present. As to relations of these periods to the prevalence of glaciers, there is not so complete harmony among geologists, but that need not affect our theory. Moreover this vast vibration seems to have had greater amplitude, in general, in proportion to nearness to the poles. This is well shown in the discussion of the matter by Professor Dana, in his Manual of Geology, pp. 552–558.

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[1] New England is stationary according to observations of the Coast Survey for 1877. (*Am. Journ. of Sci.* (III), XXI, p. 77.) The rising of a few of the other countries given above, is also disputed. In such cases I have tried to weigh the evidence.

[2] Possibly the numerous islands in the tropical Pacific which Professor Dana reports as at present rising or stationary (*vide* Corals and Coral islands) are to be referred to such a case.

For the tropical regions in the same periods we cannot say as much. Comparatively few observations are reported which have any decisive bearing on their movements. It will be readily seen that we should expect a general elevation immediately preceding the present epoch.

Wallace, from his profound studies of the fauna and flora of Java, Sumatra and Borneo, concludes that they were submerged during the Miocene, but "at some later period a gradual elevation occurred, which ultimately united them with the continent. This may have continued till the glacial period in the northern hemisphere, during the severest part of which a few Himalayan species of birds and mammals may have been driven southward. Java was first separated by subsidence, then a little later Sumatra and Borneo."[1] He, from similar data, judges Celebes to be a fragment of the great eastern continent in perhaps Miocene times. This suffices to show a vibration in tropical areas, such as our theory demands, except that its time is not definitely determined. It seems not improbable that they may have been elevated through the Pliocene, been depressed during the Glacial epoch, then partially elevated during the Champlain, and again depressed, perhaps to a greater extent, which movement continues to the present, except where counteracted by volcanic influences.

From New Guinea and Australia we find nothing recorded which will throw any light on their movements, in the epoch preceding the present. Nor can we hope, perhaps, to find anything in the coral islands bearing on this stage of our case. It is barely possible that some of them which are much elevated, as Elizabeth island, Metia, Rurutu and others (*vide* Dana's Coral islands), may ultimately prove to be monuments of such an elevation as well as of a still earlier depression, deeper than that of the present. And if it be incredulously asked, What, then, has become of the former tops of other islands, which certainly must have been in existence, to form the bases of many of the present atolls, and for a connecting stage between the successive depressions according to our theory? it may be replied, that they may have been carried away by the waves in the period of upheaval. We may, perhaps, see some evidence of this, where some atolls are themselves arranged in a ring-like form, as though an older atoll had been shattered, and each remnant became the center of a smaller one, as is the case in Atoll Ari, and in the Maldives generally.

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[1] Island Life, p. 353.

Falling into the same line of argument is Darwin's observation of the terraces, on the Island of San Lorenzo, opposite Callao. He found there evidence of three terraces, and on the lowest, at an altitude of eighty-five feet, recent shells, but they were deeply corroded, and had "a much older and more decayed appearance, than those at a height of 500–600 feet on the coast of Chili."

Professor Dana, in his work on coral islands, argues strongly in favor of recent tropical depressions, in not only the Pacific and Indian oceans, but in the Atlantic also, even including many areas which Darwin considers to have been elevated. He also considers them as being compensated by elevations in higher latitudes preceding or during the Glacial period.

As before suggested, it does not seem to the writer necessary to assume a continuous subsidence from that time, perhaps interrupted with periods of stability, but rather that there may have been at least one time of considerable elevation intervening. Our hypothesis may assist in explaining certain problematic questions of this age, viz.: The occurrence of European plants in Australia, by the elevation of the tropical regions, at the proper time to form a bridge between the Palearctic and Australian provinces, and the occurrence of numerous edentates in North America towards the end of the Glacial period, by the elevation of the regions between North and South America.

3. Changes in Earlier Ages.

It is quite generally recognized by geologists, that in earlier times the land and sea were subject to oscillations of continental extent. Indeed, Europe and North America seem to have risen and subsided contemporaneously. Considering that conglomerates indicate recent elevation of the land, and perhaps a culmination of elevation, and that heavy deposits of limestone, on the other hand, mark a continued submergence, we may note nine great vibrations, to say nothing of several minor ones. We may enumerate the periods of depression, as the Huronian, Trenton, Niagara, Lower Helderberg (?), Corniferous, Sub-Carboniferous, Permian (?), Cretaceous, Later Eocene, and the Champlain already mentioned.[1] When we remember that these formations have been studied almost exclusively in the higher latitudes, and that we have seen reason, from later epochs, to believe motions of opposite phase, in lower latitudes, we may find it, as far as we now know, strong corroboration in our theory.

Before leaving this point, the writer would say, that after elaborating the theory as given above, he was pleased to find an almost identical view expressed by Dr. Dawson,[2] as follows: "We have seen, in the progress of our inquiries, that the movements of the continents seem to have occurred with accelerated rapidity in the more modern periods. We have also seen that these movements might depend on the slow contraction of the earth's crust, due to cooling, but that the effects of this contraction might manifest themselves only at intervals. We have further seen that the gradual retardation of the rotation of the earth furnishes a cause capable of producing elevation and subsidence of the land, and that this also must be manifested at longer or shorter intervals, according to the strength and resisting power of the crust. Under the influence of this retardation, so long as the crust of the earth does not give way, the waters would be driven toward the poles, and the northern land would be submerged, but as soon as the tension became so great as to rupture the solid shell, the equatorial regions would collapse, and the northern land would be again raised." This corroborating view, from so experienced a geologist, guarantees that the ideas presented above are not wholly visionary.

III. We pass on to indicate briefly certain important lines of investigation in connection with our subject.

(1.) A re-examination, from a mathematical and physical standpoint, of the possibility of such contraction of the earth, and such variation of its ellipticity, as this theory requires. Sir William Thompson thinks any considerable change of ellipticity in geological ages impossible. G. H. Darwin thinks the diminution of ellipticity in recent times not impossible.[1] Fisher, Dutton and others [2] considering the matter from different standpoints, declare against any considerable amount of contraction since the formation of the first crust. Mallet has estimated it at probably as great a figure as any one.

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[1] Compare Dawson, Story of Earth and Man, p. 178; Shaler, chapter on Ancient Glacial Periods, in his recent work on Glaciers; also, Dana's Manual.

[2] Story of Earth and Man, p. 291.

(2.) A more careful noting of the height of marine terraces in all parts of the world, and an accurate determining of their relative ages, as indicated by their fossils and degree of preservation. The common remark, " containing recent shells," is of little value.

(3.) A more careful study of the geological formations in tropical regions, and an especial noting of any signs of their alternating with similar formations outside. This, probably, may as readily be told, as in any way, by the comparative development of their forms of life.

(4.) A special study of the areas occupying the neutral ground, to discover, if possible, the over-lapping of formations, alternately from the higher and lower latitudes. Such areas should be chosen as have been as little disturbed by local causes as any. Those presumably the more favorable are Texas and Eastern Mexico. The Pampas and Australia. India, North and South Africa, are less favorable, at least, for the recent formations. The great variability of the neutral belts should be remembered, and the consequent extensive overlapping of strata. These areas may be found especially instructive, not only in determining the succession of strata, but in filling up the gaps in the series, both in the geological strata and the forms of life.

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ON THE BITE OF THE NORTH AMERICAN CORAL SNAKES (GENUS ELAPS).[3]

BY FREDERICK W. TRUE.

1. The facts presented below indicate clearly, I believe, that the North American coral snakes possess the poisonous characteristics of the family to a considerable degree, rendering their

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[1] Vid. Nature, Jan. 5th, 1882.

[2] Vid. Fisher's Physics of the Earth's Crust, p. 75.

[3] Read before the Biological Society of Washington, Oct. 13, 1882.